APPARATUS FOR DETECTING RAMAN GAIN IN AN OPTICAL TRANSMISSION SYSTEM

Field of the Invention:

The invention relates to a sensor responsive to a dense band of signals transported over an optical transmission system.

Background of the Invention:

As is well known, when a number of optical channels are propagating over an optical fiber, so-called stimulated Raman scattering (gain) may cause an optical channel to interact with a channel of a longer wavelength. Such interaction causes the power in the shorter wavelength channel to decrease and power in the longer wavelength channel to increase. In effect, the power in the shorter wavelength channels is "pumped" into the longer wavelength channels. The most pronounced effects occur when the channels are separated by about 15 THz. When an appreciable number of channels are transmitted over an optical fiber with a high level of power per channel, then the effect tilts the power divergence between the channels significantly to the channels of longer wavelengths.

The effect of Raman scattering increases when more than one band of optical channels are transported over an optical fiber, e.g., C and L bands. In that instance, the effect is approximately linear with channel separation, and may be determined by summing the contribution provided by each of the channels. If the different bands of channels are produced by different sources, then the possibility arises in which an entire band of channels may be suddenly lost or present based on whether the corresponding source has suddenly failed or come on line. This problem would be manifested by a

sudden change in the spectra of the other bands, which may significantly increase the error rate of those bands. Consequently, the affected bands need to be adjusted immediately, e.g., within microseconds, to changes in average signal level and tilt.

The prior art uses an optical spectrum analyzer to generate the information needed to make the above adjustments.

However, what is needed is a sensor that quickly analyzes a band of channels to quickly detect changes in power level due to Raman scattering/pumping whenever the number of channels in another band of channels changes.

Summary of the Invention:

We have recognized that the effect of Raman scattering may be determined very quickly by determining the ratio between the total power and a real-time weighted total power.

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More specifically, a sensor processes a group of incoming channel signals to generate a first signal, P_0, that is indicative of the total power across the group channel signals , and a second signal, P_1, that is indicative of the total power across the group of channels after the group of channel signals has been subjected to a predetermined weighting function The system then offsets, as a function of the first and second signals, any Raman scattering that may be affecting the channels signals.

Brief Description of the Drawings:

In the drawings:

FIG. 1 illustrates signals in different bands and is useful in defining different terms discussed below;

FIG. 2 illustrates in block diagram form an optical system in which the principles of the invention may be practiced;

FIG. 3 is broad block diagram of the sensor of FIG. 2; and

FIG. 4 illustrates an alternative way of generating weighted signals, in accordance with an aspect of the invention.

General Description:

We have recognized that, in accordance with various aspects of the invention, that the effect that an arbitrary band of channels may have on another channel due to Raman scattering may be simulated by a single channel having an effective power of P_E and an effective wavelength of λ_E.

If all of the signal bands are within a particular bandwidth, e.g., within the range of 13 THz to 16 THz, then the Raman interaction between any two channels may be described approximately by the following relationship:

$$P_R = \gamma \cdot I_L I_S (\lambda_L - \lambda_S) \qquad \textbf{(1)}$$

where γ is the coefficient of the Raman Interaction, I_L and I_S (averaged over all polarizations) are the intensities of the longest and shortest wavelength channels, and λ_L and λ_S are the wavelengths. The effect of j channels in a single band on a single channel having a wavelength of λ_L may be determined by summing each such effect as follows:

$$P_R = \gamma \sum_j I_L I_j (\lambda_L - \lambda_j) \qquad \textbf{(2)}$$

Recognizing that equation (2) may be separated into two sums, then:

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$$P_R = \gamma \cdot I_L \lambda_L \sum_j I_j - \gamma \cdot I_L \sum_j I_j \lambda_j \tag{3}$$

where the first sum is the total power in the band, P_0.

Referring to FIG. 1 which shows signals in different bands, we define $\Delta\lambda_j = \lambda_j - \lambda_{min}$ and $\Delta\lambda_B = \lambda_{max} - \lambda_{min}$ so that equation (3) may be rewritten as follows:

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$$P_R = \gamma \cdot I_L (\lambda_L - \lambda_{\min}) P_0 - \gamma \cdot I_L \Delta\lambda_B \sum_j \frac{I_j \Delta\lambda_j}{\Delta\lambda_B} \tag{4}$$

Note that the above summation is the sum of the powers in the band weighted linearly by the distance from the beginning of the band. Other than P_0, the remaining terms are constants. Therefore, equation (4) may be rewritten as follows:

$$P_R = C_0 P_0 + C_1 P_1 \tag{5}$$

where P_1 is the weighted sum. The full effect of Raman pumping may then be obtained by apparatus which provides P_0 and P_1 directly in real time.

Detailed Description:

An illustrative optical transmission system embodying the principles of the invention is shown in simplified form in FIG. 2. The optical system, more particularly, includes head-end node 100 having, inter alia, a plurality of laser transmitters (XMTR) 110-1 through 110-n, multiplexer 115 and optical amplifier 120. Each of the transmitters generates an information bearing optical signal and supplies the signal to a respective input of multiplexer 115.

The optical signals, λ_1 through λ_n, so generated may constitute two different bands of optical signals/channels such that signals λ_1 and λ_n would respectively have the longest and shortest wavelengths of the signals in the two different bands. Multiplexer 115 multiplexes the signals to an output extending to optical amplifier (OA), which amplifies and outputs the multiplexed signals to optical path segment 130 extending to a next downstream node. A number of downstream/ intermediate nodes may be disposed along optical transmission path 130 as represented by the dashed portions of segments 130. Node 200 represents each such intermediate node. Thus, the following discussion of node 200 equally pertains to each of the other similarly arranged nodes.

Node 200, includes, inter alia, optical amplifier 210 that amplifies an optical signal received via path 130 and outputs the amplified signal via splitter 215 to other processing equipment, e.g., a demultiplexer, signal translation units, add/drop apparatus, etc., as represented by the dashed line 230 in node 200. Optical signal splitter 215 supplies a small portion of the amplified signal to sensor 220 and supplies the remainder of the amplified signal to the other equipment for further processing. Sensor 220 processes its portion of the amplified signal to determine if the signal had been tilted as a result of Raman scattering occurring along the transmission path 130. Sensor 220 supplies the results of its determination to control circuit 225, which then directs optical amplifier 235 to tilt the signal that it receives at its input in an opposite direction to offset the effect of the Raman scattering, if needed.

Sensor 220, shown in more detail in FIG. 3 includes, inter alia, band pass filter 10 which is tuned to one of the bands of signals received via path

221. Assuming that filter 10 is tuned to the L-band of signals, then those signals pass through filter 10, while signals of different bands/wavelengths are rejected. Splitter 15 splits the signal emerging from filter 10 into two signals, respectively supplying substantially equal portions of the split signal to total power detector 40-1 via path 17 and to port 20-1 of conventional optical signal circulator 20 via path 16. As is well-know a signal received at a circulator port is circulated in a particular direction, e.g., counterclockwise, and outputted at a next port. For example, a signal received at port 20-1 is circulated to a next port, e.g., port 20-2, and outputted at that port; a signal received at port 20-2 is similarly circulated to a next port, e.g., port 20-3, and outputted at that port, and so on. Thus, the L-band signal received at port 20-1 is circulated to and outputted at port 20-2, where it is presented via path 31 to section 32-1 of conventional Dragone router 30. Section 32-1 of Dragone router 30, in a conventional manner, demultiplexes the signal that it receives via path 31 and outputs the component signals forming the band of signals to respective output ports extending to section 32-2 of Dragone router 30. Section 32-2 of Dragone router outputs the demultiplexed signals, λ_1 through λ_n of the filtered band of signal, to respective inputs of Variable Reflection Filter (VRF) 35. VRF 35 reflects an optical signal that it receives at one of its inputs proportional to the wavelength of the signal. Thus, the level of reflection provided by filter 35 linearly increases across a band of signal, from the longest wavelength, λ_1, to the shortest wavelength, λ_n, such that the former signal is reflected the most while the latter signal is reflected the least.

For example, the reflectivity might be $R(\lambda) = (\lambda - \lambda_{min})/(\lambda_{max}-\lambda_{min})$, which ranges from 0 (for the shortest wavelength) to 1 (for the longest wavelength).

In this way, the signals forming the band are linearly weighted proportional to their respective wavelengths. The reflected, weighted signals are returned to Dragone section 32-2, which then routes the weighted signals to Dragone section 32-1. The latter section then multiplexes the weighted signals onto path 31 extending to port 20-2 of circulator 20. As pointed out above, signals received at port 20-2 are circulated to and outputted at port 20-3 of circulator 20, where the multiplexed weighted signal is presented to weighted power detector 40-2. Weighted power detector 40-2, in a conventional manner, detects the level of power in the signal that it receives and outputs a signal, P_1, indicative thereof to amplifier 45-2. (Detector 40-2 may do this using a conventional light detector that outputs a signal having a power level proportional to the level of the light signal that it receives at its input.) Similarly, total power detector 40-1 detects the level of power in the (unweighted) signal that it receives and outputs a signal, P_0, indicative thereof to amplifier 45-1. Amplifier 45-1 multiples the signal P_0 by a constant C_0 (represented by the value of resistor R1) to form the sought after signal C_0P_0. Similarly, amplifier 45-2 multiplies the signal P_1 by a constant C_1 (represented by resistor R2) to form the other sough-after signal C_1P_1. Summing amplifier 50 sums the outputs of amplifiers 45-1 and 45-2 to combine signals C_0P_0 and $C_1 P_1$ as a linear weighted sum to form above-defined signal P_R. The latter signal is then supplied to controller 225, which, as mentioned above, adjusts the tilt of the signal being amplified by amplifier 235 to correct for the effect of Raman scattering, if needed.

In accordance an aspect of the invention, the values of resistors R1 and R2 are calibrated for a given installation at the factory using a signal

comprising all of the intended signals in the band, e.g., the L band, and then using just half of those signals. More specifically, the calibration maybe done using wavelengths of λ_{max} and λ_{min}. For λ_{max}, P_0 is set to equal P_1, and for λ_{min}, P1 is set to 0. To determine the effective power, P_E, and wavelength, λ_E, $P_E = P_0$ and $\lambda_E = \lambda_{min} + \Delta\lambda_B P_1/P_0$.

In an alternative embodiment of the invention, a variable loss device in combination with a reflector may be used in place of variable reflection filter (VRF) 35, as shown in FIG. 4. Specifically, the amount of loss inserted in each path of the demultiplexed signals is proportional to the wavelength of the signal. That is, the most loss is inserted in the path of the signal having the shortest wavelength and most loss is inserted in the path of the signal having the longest wavelength. The signals are then reflected/returned to Dragone section 32-2 by an optical reflector as shown. In this way the signals are weighted according to the amount of loss that they encounter on their way to the reflector and on their return to Dragone section 32-2.

(Note that for a Dragone router having a sufficiently large free-spectral range (FSR), the intensities in section 32-2 are uniform across all channels. Also note, that for a smaller FSR, the intensities may be approximated by a Gaussian function. As such, a Dragone router having a large FSR is preferable over a Dragone router having a smaller FSR. However, if a router of the latter type is used, then R(λ) will need to include the Gaussian Shaping factor.

Further note, that other wavelength dependent effects may be handled using other R(λ) functions in the reflector. For example, a polarization dependent sensor may be implemented by placing a polarization splitter

between filter 10 and splitter 15 (FIG. 3) and duplicating the circuitry that follows splitter 15 so that sensor values may be obtained for each polarization.)

It will thus be appreciated that, although the invention illustrated herein is described in the context of a specific illustrative embodiment, those skilled in the art will be able to devise numerous alternative arrangements which, although, not explicitly shown or described herein, nevertheless, embody the principles of the invention and are within its spirit and scope. For example, the inventive sensor may be used to deal with transmission impairments other than Raman scattering.